PB83-140848

The Phosphorus-Chlorophyll 'a' Relationship in Periphytic Communities in a Controlled Ecosystem

(U.S.) Environmental Research Lab.
Athens, GA

1982

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TECHNICAL REPORT DATA
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1. REPORT NO.	2.	3.
EPA-600/J-81-324	Journal Article	PB83-140848

4. TITLE AND SUBTITLE	5. REPORT DATE
The Phosphorus-Chlorophyll a Relationship in Periphytic Communities in a Controlled Ecosystem	1982
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Joseph A. Krewer and Harvey W. Holm*	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Bionetics Corporation, USEPA, Athens GA 30613	CCULIA
	11. CONTRACT/GRANT NO.
*Environmental Research Laboratory, USEPA, Athens GA 30613	
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Environmental Research Laboratory--Athens GA Office of Research and Development U.S. Environmental Protection Agency Athens GA 30613	Journal Article
	14. SPONSORING AGENCY CODE
	EPA/600/01

15. SUPPLEMENTARY NOTES

Published in Hydrobiologia. 94(2):173-176, 1982

Contact: H.W. Holm, 8-250-3103

16. ABSTRACT

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASIFIED	5
	20. SECURITY CLASS *(This page)*	22. PRICE
	UNCLASSIFIED	

EPA Form 2220-1 (9-73)

EPA-600/J-81-324
JOURNAL ARTICLE

The phosphorus-chlorophyll *a* relationship in periphytic communities in a controlled ecosystem

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Keywords: phosphorus, chlorophyll *a,* microcosm

Abstract

The correlation between total dissolved phosphorus input concentrations and periphytic chlorophyll *a* concentrations was examined after a four-week colonization period on artificial substrates in large, continuous-flow microcosms. A significant correlation was established; the data produced a linear regression and substantiated a recently proposed curvilinear regression analysis. The curvilinear equation can be used in future microcosm studies as a predictive aid for regulating phosphorus input concentrations.

Introduction

The relationship between phosphorus concentration and chlorophyll *a* production has been the subject of considerable research in both lakes and laboratory microcosms. Several authors have found the maximum spring or winter concentrations of phosphorus in lakes to be directly proportional to the summer chlorophyll *a* concentration of the phytoplankton standing crop (Sakamoto 1966; Lund 1970; Dillon & Rigler 1974; Hickman 1980). It has also been observed that lakes exhibit concentrations of chlorophyll *a,* nitrogen, and carbon proportional to phosphorus concentrations, based on mean annual values (Schindler 1978). The proportional relationship of phosphorus to chlorophyll has also been demonstrated in both closed microcosms and simple flow-through ecosystems (Fraleigh 1978). Because most research on phosphorus-chlorophyll *a* relationships has been conducted on planktonic communities, the objective of our study was to determine whether the relationship could also be verified in a periphyton-dominated microcosm community. Our study, conducted from 5 August to 14 October 1980, was part of an extensive year-long examination of the aquatic fate of pollutants using the Aquatic Ecosystem Simulator (AEcoS) at the USEPA's Environmental Research Laboratory in Athens, Georgia.

Facility description

AEcoS is a controlled environment chamber that houses a 19.5 m long, 46 cm wide, 51 cm deep 'U-shaped' flume. The flume is divided into two independent channels that are treated as replicates (designated A and B), each subdivided into eight 250-l compartments referred to as Continuously Stirred Tank Reactors (CSTRs). Each CSTR is equipped with an outlet weir such that the effluent from an upstream CSTR constitutes the influent for the next downstream CSTR. The flume, constructed of Plexiglas [R*], is lined with 4-mil-thick, adhesive-backed Teflon[R]. Uniform mixing in each CSTR is accomplished using Teflon-covered Plexiglas paddlewheels that are suspended longitudinally in each CSTR and rotated at 0.04 m/s, as measured at the circumference.

* Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Environmental Protection Agency.

Hydrobiologia 94, 173–176 (1982). 0018-8158/82/0942-0173/$00.80.
Dr W. Junk Publishers, The Hague. Printed in The Netherlands.

Water flow in the channels was maintained at 500 l/day at 20 °C yielding a retention time of 12 h/CSTR. Well-water, purified by reverse osmosis and deionization, and irradiated with UV light to minimize endogenous microbial activity prior to introduction into the channel, was used in the study. The channels were illuminated with 2 000 ft-c of fluorescent light on a 12-h light/dark cycle. Water chemistries of CSTRs were maintained by introducing nutrient concentrates continuously into CSTRs 3 and 6 using silicone tubing and peristaltic pumps. CSTRs 1 and 2 received no nutrient input, so only CSTRs 3 through 8 for Channels A and B were used in the phosphorus-chlorophyll *a* study. In summary, then, AEcoS consisted of 12 flow-through microcosms with various phosphorus input concentrations but identical environmental conditions such as flow rate, temperature, and photoperiod.

Methods

Teflon-covered Plexiglas strips were used as a substrate for periphytic growth, which was dominated primarily by filamentous algae of the genera *Oscillatoria* and *Oedogonium*. The colonized strips were removed from each CSTR after four weeks, which is a recommended exposure time for artificial substrates in eutrophic waters of low flow (Collins & Weber 1978), and the biomass was scraped off. Using the 90% acetone extraction technique with a B. Braun cell homogenizer, chlorophyll *a* concentrations corrected for phaeophyton *a* were determined with a G. K. Turner and Assoc. (Model 111) flourometer (Strickland & Parsons 1968).

Input concentrations of total dissolved phosphorus for the CSTRs were determined from bi-weekly samplings, and mean phosphorus input values were calculated for the four-week colonization period. The water samples were filtered through 0.45 μm Gelman HT-450 filters, and the filtrate was digested using a modified acid-persulfate digestion procedure in an autoclave for 30 min and analyzed by the ascorbic acid-ammonium molybdate method on a Technicon AutoAnalyzer II (USEPA 1979). The sampling and analysis of total particulate phosphorus was not included in the design of the year-long study of pollutant fate; therefore data on TPP are not available. Lund (1970) examined the relationship between maximum winter orthophosphorus and maximum summer chlorophyll *a* concentrations and postulated that a closer relationship would have been obtained if total phosphorus concentrations had been used. Likewise, the addition of total particulate phosphorus concentrations in this study would probably increase any observed correlation between phosphorus and chlorophyll *a*, particularly for CSTRs 7 and 8, which had periphytic growth greater than would be expected from total dissolved phosphorus inputs alone. Particulate inflow from the heavily colonized CSTR 6 could account for this discrepancy.

Results and discussion

The mean total dissolved phosphorus input concentrations and the periphytic chlorophyll *a* concentrations after 4 weeks in each CSTR (Table 1) were used to develop the log-log linear regressions shown in Fig. 1. Channels A and B are presented separately to demonstrate the replicability of the duplicate CSTRs. The linear regression for both channels combined is also presented to give the overall relationship of phosphorus to chlorophyll *a*

Table 1. Mean total dissolved phosphorus and chlorophyll *a* concentrations for each CSTR in AEcoS.

Period colonized 1980	CSTR	TDP (S.D.), (mg/l)	Chl *a* (S.D.), (μg/cm²)
7/7–8/5	A3	0.017 (0.002)	4.2 (0.7)
	B3	0.017 (0.002)	5.7 (2.9)
7/14–8/12	A4	0.005 (0.001)	1.4 (0.5)
	B4	0.005 (0.001)	3.4 (0.4)
7/21–8/19	A5	0.004 (0.001)	0.3 (0.1)
	B5	0.004 (0.001)	0.4 (0.1)
7/28–8/26	A6	0.134 (0.006)	16.8 (5.3)
	B6	0.135 (0.006)	21.6 (8.4)
8/11–9/9	A7	0.021 (0.008)	17.1 (5.3)
	B7	0.042 (0.012)	18.5 (6.3)
8/18–9/16	A8	0.024 (0.005)	14.2 (0.8)
	B8	0.069 (0.011)	10.9 (1.2)
8/25–9/23	A3	0.017 (0.002)	6.4 (0.3)
	B3	0.017 (0.002)	5.2 (1.3)
9/1–9/30	A4	0.004 (0.001)	2.9 (0.4)
	B4	0.004 (0.001)	1.6 (0.4)
9/8–10/7	A5	0.003 (0.001)	0.8 (0.1)
	B5	0.003 (0.000)	0.6 (0.0)
9/15–10/14	A6	0.133 (0.006)	37.5 (18.0)
	B6	0.133 (0.006)	14.8 (7.8)

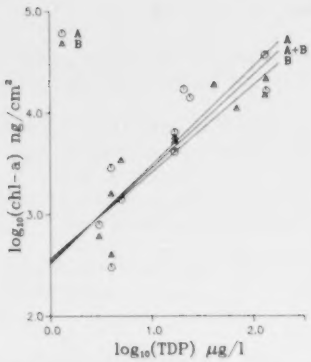

Fig. 1. Linear relationship between periphytic chlorophyll *a* concentration and total dissolved phosphorus input concentration for Channel A, Channel B, and Channels A and B combined.

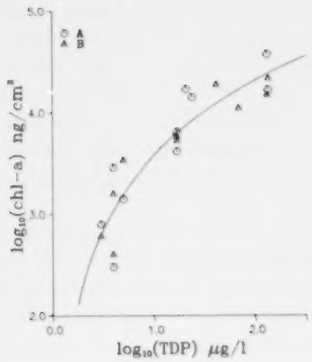

Fig. 2. Curvilinear relationship between periphytic chlorophyll *a* concentration and total dissolved phosphorus input concentration for Channels A and B combined.

in AEcoS. The linear regression equations are

1. Channel A: $\log_{10}(\text{chl } a) = 0.973 \log_{10}(\text{P}) + 2.512$ ($r = 0.87$, $p. < 0.001$)
2. Channel B: $\log_{10}(\text{chl } a = 0.855 \log_{10}(\text{P}) + 2.566$ ($r = 0.91$, $p < 0.001$)
3. Channel A and B: $\log_{10}(\text{chl } a) = 0.905 \log_{10}(\text{P}) + 2.548$ ($r = 0.88$, $p > 0.001$).

Literature values for correlation coefficients of linear regressions of total phosphorus versus chlorophyll *a* from planktonic investigations include $r = 0.67$ (Hickman 1980), $r = 0.86$ (Schindler 1977), and $r = 0.98$ (Dillon & Rigler 1974); r values from the present study reflect a similar strong correlation.

In an effort to demonstrate an even greater correlation between the phosphorus input concentration and the periphytic chlorophyll *a* concentrations, two factors which might alter the linearity of the relationship were examined. These were limitations of nitrogen and light to the community. Dillon & Rigler (1974) used the data of Sakamoto (1966) to demonstrate that the greatest deviations from the regression line of phosphorus versus chlorophyll *a* occurred in lakes with low N:P ratios. The N:P input ratios of our study, based on total dissolved nitrogen and total dissolved phosphorus input concentrations, varied from 14.8 to 81.3, none falling below the N:P ratio of 12 considered by Dillon & Rigler (1974) to indicate nitrogen limitation. Hickman (1980) observed that, as lakes progress from oligotrophy to eutrophy, the decrease in light penetration and depth of the euphotic zone cause the standing crop of phytoplankton to approach its theoretical maximum as a result of self-shading. He suggested that a curvilinear relationship between phosphorus and chlorophyll *a* is more ecologically appropriate than a linear relationship and derived the equation:

$$\log_{10}(\text{chloro } a) = 3.27 \log_{10}(\log_{10}[\text{P}] + 0.542$$

where $r = 0.842$, $P > 0.001$. The data for Channels A and B combined (Table 1) were used to determine whether such a relationship exists in the present investigation. The following curvilinear equation was derived

$$\log_{10}(\text{chl } a) = 2.439 \log_{10}(\log_{10}[\text{TDP}]) + 3.583$$

where $r = 0.91$, $p < 0.001$ (Fig. 2). Therefore the curvilinear relationship ($r = 0.91$) shows an even higher correlation than the linear relationship ($r = 0.88$) in our study, as it did in Hickman's (1980) for natural planktonic communities.

In addition to self-shading, the periphytic organisms studied here are affected by several factors that are not relevant to planktonic organisms but may affect the phosphorus-chlorophyll relationship. Plankton are continuously surrounded by available gases and nutrients as they change position in the water column. Periphyton, being sessile, are subject to spatial limitations on the substrate as the periphyton mat increases in thickness. The diffusion of gases and nutrients to periphytic organisms is restricted, so that even if biomass continues to accumulate, only the upper layer of the periphytic mass is photosynthetically active (McIntyre & Phinney 1964; Sumner & Fisher 1979). The correc-

tion of chlorophyll *a* concentration for phaeophytin *a* ensures that only biologically active pigments are measured. Therefore, as Fig. 2 illustrates, chlorophyll *a* concentrations began to level off despite increasing total dissolved phosphorus inputs, and the curvilinear relationship does seem more ecologically appropriate for these periphytic communities.

A problem that arises in long-term microcosm projects is the disproportionate influence on the dynamics of the system by attached communities on the bottom and sides of the microcosm (Dudzik *et al.* 1979). The difficulty of sampling these communities and of controlling the sloughing of attached algal mats into the water column has also arisen in AEcoS. The curvilinear relationship derived here should provide our system modelers and others pursuing similar research with a means of predicting periphytic development from phosphorus input concentrations in order to limit unnecessary periphytic growth. The general utility of this relationship will be tested in future experiments.

Summary

The linear relationship of total phosphorus concentrations versus phytoplankton chlorophyll *a* concentrations is a well established concept in current ecological theory. The present study extends this relationship to total dissolved phosphorus input concentrations versus periphytic chlorophyll *a* concentrations in a large-scale microcosm and finds a significant correlation ($r = 0.88$).

In addition, a recently proposed curvilinear relationship (Hickman 1980) has been applied to the data and provides a higher correlation ($r = 0.91$). The curvilinear equation derived here can be of use to future microcosm studies as a predictive aid for regulating phosphorus input concentrations.

Acknowledgments

We would like to thank the Bionetics and AEcoS staffs for their help in the data collection and comments on this manuscript, particularly Chris Langner, Tom Hall, Paul Hendrix, and Jim Hamala.

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Received 17 July 1981; accepted 10 November 1981.